PRELIMINARY RESULTS OF STUDY OF COMPOSITE LINER FIELD PERFORMANCE

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ABSTRACT

This paper presents preliminary results of a study of field performance of composite liners. The purpose of the study is to evaluate the ability of composite liners to contain and minimize leachate migration when used as top liners of double-lined landfills and surface impoundments. This paper addresses preliminary results for double-lined municipal solid waste (MSW) landfills. Composite liners consisting of a geomembrane upper component and a compacted clay liner (CCL) or geosynthetic clay liner (GCL) lower component were considered in the study. Data on flow volumes and flow constituents for the leachate collection and removal system (LCRS) and the leak detection system (LDS) components of the double liner system were obtained and reviewed in an attempt to assess the level of liquid containment provided by the top composite liner. Data from eight MSW landfills with monitoring periods of up to eight years were considered. Preliminary results indicate that composite liners are performing well and are effective in containing leachate.

INTRODUCTION

Landfills have long been used for the permanent land disposal of MSW. United States federal and state regulations require that these facilities be designed to function for an active life, plus a post-closure period, typically 30 years. In most cases, however, waste will remain in the landfill for a much longer period of time, possibly hundreds or thousands of years. One potential environmental impact of landfills is ground-water contamination resulting from landfill leachate. In order to protect ground water, landfill leachate containment and collection systems must perform satisfactorily during the entire period of significant leachate generation. Liner systems are typically used to contain and collect landfill leachate.

A liner system consists of a combination of one or more drainage layers and low-permeability barrier layers (i.e., liners). The functions of the liners and drainage layers are complementary. The liner impedes the migration of leachate out of the landfill and improves the performance of any overlying drainage layer. The drainage layer limits the buildup of hydraulic head on the underlying liner and conveys to a sump the liquid that percolates into the layer. The objective of this paper is to present preliminary results of a study of the field performance of composite liners. This paper especially addresses data for top composite liners in double-liner systems of MSW landfills.

Typical components of the double-liner systems included in this study are illustrated in Figure 1. From top to bottom, the components shown in Figure 1 are:

- LCRS, which consists of a permeable soil and/or geosynthetic drainage system, and possibly a network of perforated liquid conveyance pipes;

- top liner, which may consist of a geomembrane alone or a composite liner having a geomembrane upper component and a low-permeability soil, or GCL, lower component;

- LDS, which consists of a permeable soil and/or geosynthetic drainage system, and possibly a network of perforated liquid conveyance pipes; and

- bottom liner, which may consist of a geomembrane alone or a composite liner having a geomembrane upper component and a low-permeability soil, or GCL, lower component.

Comparison of the rates of flow into the LCRS and LDS of a double-lined MSW landfill can be used to quantify the performance of the top liner (in terms of ability to impede advective transport of liquid through the liner). Comparison of the chemical quality of liquids in the LCRS and LDS can be used to evaluate the sources of liquid flow into the LDS and to assess the ability of the top liner to contain chemicals present in the LCRS.

As part of an ongoing research investigation for the United States Environmental Protection Agency (USEPA), the authors have collected data for a wide variety of double-lined waste management units located throughout the United States. Currently, the database includes information on 194 waste management units at 54 double-lined landfills and 17 ponds at 6 double-lined surface impoundments. The data collected includes information on: (i) facility general information (including location, average annual rainfall, subsurface soil types, ground-water separation distance, etc.); (ii) cell general information (including cell area, type of waste, height of waste, etc.); (iii) details of the liner system and cover system (including type, thickness, and hydraulic conductivity of each layer); and (iv) LCRS and LDS flow qualities and liquid quality. Data analysis is currently in progress. A subset of the database, relating to MSW landfills with composite top liners, is analyzed in this paper to draw conclusions on the performance of composite liners. The units considered have significant data available on LCRS and LDS flow rate and liquid chemistry for monitoring periods of up to eight years.

REVIEW OF PREVIOUS STUDIES

Overview

The performance of composite top liners can be assessed by evaluating flows in the LDSs of double-lined landfills and surface impoundments. To make the evaluation, consideration must be given to the potential sources of liquid in the LDS. Gross et al. [1990] described the potential sources of LDS flow, which are (Figure 2): (i) leakage through the top liner; (ii) drainage of water (mostly rainwater) that infiltrates the leakage detection layer during construction but does not drain to the LDS sump until after start of facility operation ("construction water"); (iii) water expelled from the LDS layer as a result of compression under the weight of the waste ("compression water"); (iv) water expelled from any CCL component of the top liner as a result of clay consolidation under the weight of the waste ("consolidation water"); and (v) for a waste management unit with its base located below the water table, groundwater infiltration through the bottom liner ("infiltration water").

Gross et al. [1990] presented the following five-step approach for evaluating the sources of LDS liquid at a specific waste management unit.

- Identify the potential sources of flow for the unit based on double-liner system design, climatic and hydrogeologic setting, and unit operating history.
- Calculate flow rates from each potential source.
- Calculate the time frame for flow from each potential source.
- Evaluate the potential sources of flow by comparing measured flow rates to calculated flow rates at specific points in time.
- Compare LCRS and LDS chemical constituent data to further establish the likely source(s) of liquid.

Previous studies of the performance of composite liners have focused on a comparison of LCRS and LDS flow data. In a few cases, chemical data were also considered. Four of these studies and their major findings are presented below.

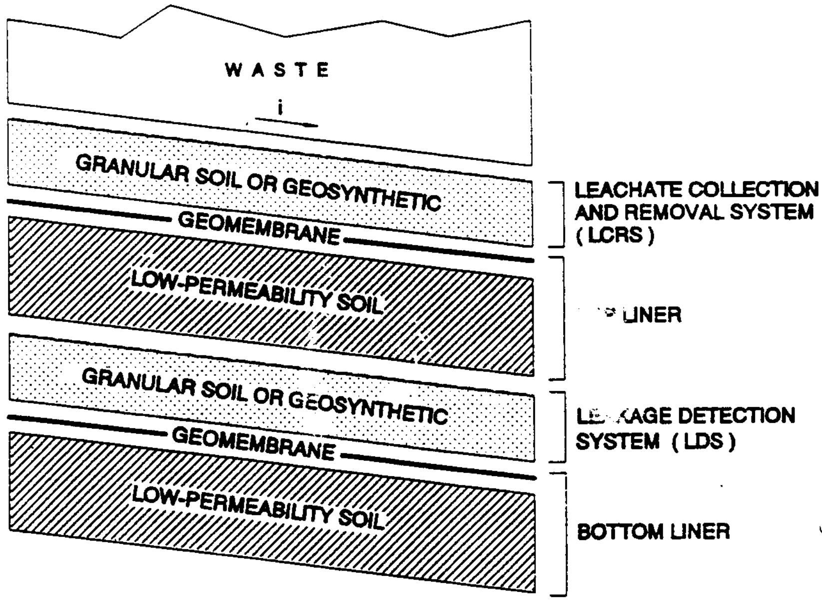

Figure 1. Components of double-liner system.

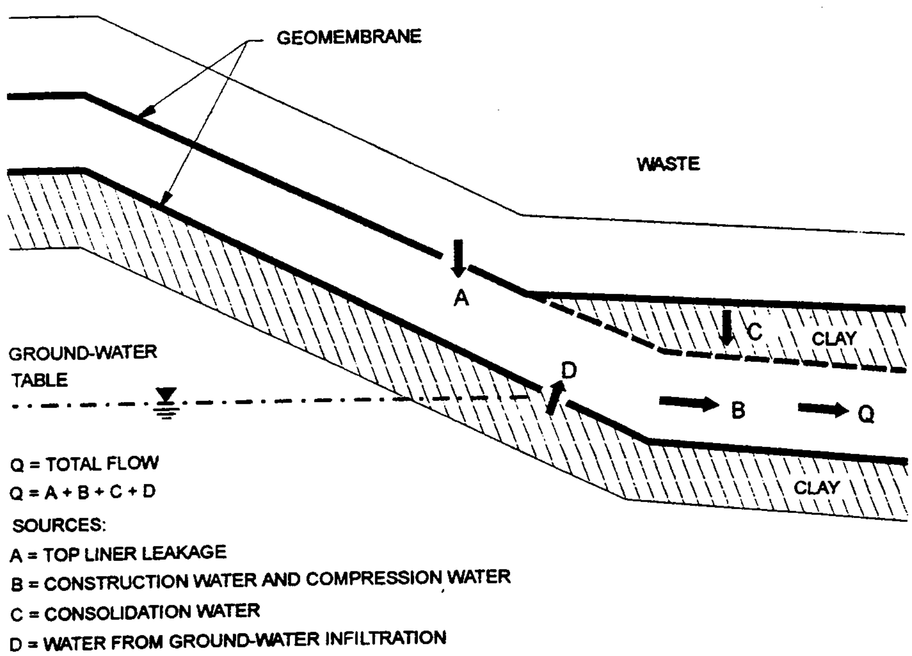

Figure 2. Sources of flow from leak detection systems (from Bonaparte et al. [1996]).

Bonaparte and Gross [1990, 1993]

Bonaparte and Gross [1990] presented data on LDS flows from 38 double-lined landfills and surface impoundments with composite top liners. The conclusions from their study for units with composite top liners are as follows:

- *"The double-lined landfills and surface impoundments in this study having a layer of compacted clay as the soil component of a composite top liner almost always exhibited flows due to consolidation water. Measured flow rates attributable to consolidation water were in the range of 20 to 840 lphd. Only very small flows were observed from the leakage detection layers of cells where the soil component of the composite top liner was a prefabricated geotextile-bentonite mat.*

- *The calculation methods presented by Gross et al. [1990] for estimating consolidation water and construction water flow rates appear reasonable for the facilities reported in this study."*

The data available to Bonaparte and Gross [1990] were not sufficient to allow them to develop definitive conclusions on the rates of any potential leakage through the composite liners. Considering all of the data from their study, the authors concluded that "the double-liner systems evaluated in this study have performed well. Leakage rates through the top liners have been low or negligible in most cases." The study database was expanded by Bonaparte and Gross [1993] as part of a USEPA-sponsored study to include data from several additional waste management units with composite top liners. The conclusions from this more recent study were essentially the same as the earlier conclusions cited above.

Feeney and Maxson [1993]

Feeney and Maxson [1993] used a methodology similar to that of Bonaparte and Gross [1990] to evaluate LDS flows from 49 double-lined cells at eight hazardous waste landfills. All but two of the units have a conventional composite top liner (i.e., a geomembrane underlain by a CCL) on the base of the landfill, and only a geomembrane on the side slopes. The two units incorporated GCLs into the composite top liner on both the landfill base and side slopes. All of the units contain a geonet LDS. All were constructed using formal CQA programs.

For 41 units with conventional composite liners on the landfill base and geomembrane liners on the landfill side slopes, average monthly LDS flow rates ranged from 0 to 310 lphd. The average flow rate for 27 of the 40 units was less than or equal to 100 lphd. Average flows over the full monitoring period were typically much less than maximum monthly averages. The authors attribute the observed LDS flows primarily to consolidation of the CCL component of the composite top liner.

LDS flows from one of the two units having a GCL in the composite top liner were negligible. This result is consistent with the findings of Bonaparte and Gross [1990] for units having composite top liners incorporating GCLs. Flow rates were larger from the LDS of the second unit having a GCL in the composite top liner and in seven of the units having a conventional composite top liner on the base of the unit and a geomembrane top liner on the side slopes. For all eight of these latter units, the authors attribute the higher flow rates to liner system damage caused by equipment operating in the units during active landfilling operations. For these eight units, average flows were much higher than the observed flows for the "undamaged" liner systems. The authors report that in all eight cases, the liner systems were repaired and the LDS flow rates decreased. It is noteworthy that eight of 49 landfill units (i.e., 16 percent) in the Feeney and Maxson study were apparently damaged as a result of landfill operations. Further investigation of the reasons for the high incidence of damage at these facilities is warranted.

Workman [1993]

Workman [1993] presented the results of monitoring of the LDS of a double-composite liner system for a MSW landfill. The top liner for the landfill consists of a geomembrane on the side slopes and a composite liner on the base. The LDS consists of a geonet drainage layer overlain by a geotextile.

Leachate detection system 4 - [illegible]

The landfill considered by Workman contains four cells, three of which have been constructed at the time of his paper. The cells were constructed between 1989 and 1992. Initial LDS flow rates in the three cells were in the range of 50 to 700 lphd, with rates at the higher end of the range being associated with the highest rate of waste disposal. Workman attributed these LDS flows to consolidation of the CCL component of the composite top liner on the base of the landfill. This conclusion was supported by the major ion chemistry of the LDS liquids which was not consistent with the chemistry of leachate from the LCRS. When filling of one cell stopped, the LDS flow rate decreased to 20 to 30 lphd. Comparison of trilinear diagrams [Piper, 1944; also described in most ground-water hydrology textbooks such as Freeze and Cherry, 1979] for the LCRS and LDS liquids does not show a correlation indicative of leakage through the top liner. Analyses of the LDS liquids from two of the cells revealed the presence of several volatile organic compounds (VOCs), including chloroethane, ethylbenzene, and trichloroethene, at low part-per-billion concentrations. Workman noted that the detected compounds are common constituents of landfill gas. He attributed the VOCs to the following:

"The presence of organic constituents in the LDS fluids should normally be a key indicator of poor liner performance, since organics are commonly present in leachate. Other potential sources of organic compounds need to be considered when evaluating liner performance. Contamination may occur during construction or other sources besides leachate. It is believed that methane is impacting the LDS liquids of Cells 1 and 4. No organic constituents have been detected in the Cell 2 LDS. The methane was first detected in Cells 1 and 4 about one year after each cell was placed in operation. This occurred about the same time that the waste reached ground level and totally covered the liner system. Since methane is not actively vented at this time and can accumulate under pressure in the leachate collection system, gradients can occur across the liner systems. The sideslopes in this landfill are particularly vulnerable. As methane penetrated the liner and cooled, the gas began to condensate and drain small quantities of liquid to the LDS sump."

Bonaparte et al. [1996]

Bonaparte et al. [1996] analyzed flow rate data, for 26 MSW management units, located at six different landfill sites, containing composite top liners consisting of a geomembrane overlying a GCL. This data was collected as part of the ongoing research investigation for the USEPA conducted by the authors. They calculated average and peak LCRS and LDS flow rates for three distinct unit development periods: (i) the "initial period of operation"; (ii) the "active period of operation"; and (iii) the "post closure period". During the "initial period of operation", LCRS flow rates are relatively high and are attributed to the occurrence of rainfall into a unit that initially contains little waste. To the extent rainfall occurs during this period, it will find its way rapidly into the LCRS. During the "active period of operation", the rate of flow into the LCRS continues to decreases and eventually stabilizes. This occurs as the amount of waste in the unit increases and as daily and intermediate layers of cover soil are placed. During the "post closure period", the final cover system further reduces infiltration of rainwater into the waste, resulting in a further reduction in LCRS flow.

Bonaparte et al. [1996] calculated mean values of average and peak LCRS and LDS flows for the 26 MSW management units. This data is presented in Table 1 of this paper. They noted that between the initial and active periods of operation, LCRS flow rates decreased one to two orders of magnitude and LDS flow rates decreased one to three orders of magnitude. Reported peak LCRS flow rates were up to five times the average, while peak LDS flow rates were up to 20 times the average. They also calculated "apparent" efficiencies for the composite top liners of the 26 MSW management units. They defined liner apparent efficiency, AE, as shown in the following equation:

$$AE\,(\%) = (1 - \text{LDS Flow Rate} / \text{LCRS Flow Rate}) \times 100 \qquad \text{(Equation 1)}$$

Table 1. Mean LCRS and LDS flow rates for MSW management units with geomembrane/GCL composite top liner from Bonaparte et al. [1996] (Note: m = mean value; σ = standard deviation; values are in liter/hectare/day).

LCRS	Number of Units	Average Flow Rate		Peak Flow Rate	
		m	σ	m	σ
Initial Period of Operation	25	5,350	3,968	14,964	11,342
Active Period of Operation	18	276	165	732	590
Post-Closure Period	4	124	-	266	-

LDS	Number of Units	Average Flow Rate		Peak Flow Rate	
		m	σ	m	σ
Initial Period of Operation	26	36.6	68.5	141.8	259.9
Active Period of Operation	19	0.7	1.1	7.7	13.7
Post-Closure Period	4	0.2	-	2.3	-

This liner efficiency is referred to as "apparent" because, as described above, flow into the LDS sump may be attributed to sources other than top liner leakage (Figure 2). If the only source of flow into the LDS sump is top liner leakage, then Equation 1 provides the "true" liner efficiency. Liner efficiency provides a measure of the effectiveness of a particular liner in limiting or preventing advective transport across the liner.

For MSW management units with sand LDSs, Bonaparte et al. [1996] found that the apparent efficiency is lowest during the initial period of operation (AE_m = 98.6 percent; where AE_m = mean apparent efficiency) and increases significantly thereafter (AE_m = 99.58 percent during the active period of operation and AE_m = 99.96 percent during the post closure period). The lower AE_m during the initial period of operation can be attributed to LDS flow from construction water. Bonaparte et al. [1995] state that for units with sand LDSs, "*calculated AE values during the active period of operation and the post-closure period may provide a reasonably accurate indication of true liner efficiency for the conditions at these units during the monitoring periods.*"

For six units with geonet LDSs, the AE_m was calculated as 99.96 percent. This value is higher than the AE_m of liners of cells with sand LDSs for the same facility operational period (i.e., 98.60 percent). This higher efficiency can be attributed to the differences in liquid storage capacity and hydraulic transmissivity between sand and geonet drainage materials. A granular drainage layer can store a much larger volume of construction water and releases this water more slowly during the initial period of operation than does a geonet drainage layer. This suggests that, during the initial period of operation, the main source of flow in a sand LDS underlying a composite top liner containing a GCL is construction water.

Bonaparte et al. [1996] conclude that "*LDS flows attributable to top liner leakage vary from 0 to 50 lphd, with most values being less than about 2 lphd. These flow rates are very low. The data shown in Table 4 suggest that the true hydraulic efficiency of a composite liner incorporating a GCL may be greater than 99.90 percent. A liner with this efficiency, when appropriately used as part of an overall liner system, can provide a very high degree of liquid containment capability.*"

<u>Conclusions from Previous Studies</u>

The following conclusions can be drawn from the previous studies regarding the hydraulic performance of composite liners.

- LDSs underlying composite liners with a CCL lower component always exhibit flow due to consolidation water. Measured LDS flow rates attributable to consolidation water are in the range of 0 to 840 lphd, with most values being less than 200 lphd. LDS flow rates decrease with time to rates on the order of 0 to 30 lphd after a significant period of active filling of the landfill.

- Very small flows were observed from the LDSs of cells where the lower component of the composite top liner was a GCL. LDS flows attributable to leakage from a composite liner incorporating a GCL vary from 0 to 50 lphd, with most values being less than about 2 lphd. The true hydraulic efficiency of composite liners with GCLs may be greater than 99.90 percent.

The studies described above evaluated the performance of composite liners primarily based on measured LDS flow rates. Except for a few studies (e.g., Bergstrom, et al. [1993] ; Workman [1993]), comparison of LCRS and LDS chemical data has not been carried out.

PRELIMINARY RESULTS FROM CURRENT STUDY

Description of Data

Data for ten MSW landfills from eight different facilities are addressed in this portion of the paper. Data is reported for LCRS and LDS flow rates and chemical parameters. Descriptions of the components of the liner systems used at these landfills are presented in Table 2 and flow rate data for the LCRSs and LDSs of the landfills are presented in Table 3. Average daily flow rates were calculated for both systems on a monthly basis by dividing the total amount of liquid extracted from the system during the month by the number of days in the month and the area of the MSW landfill. Flow rates are reported in units of liter/hectare/day (lphd) for time increments of approximately twelve months. The volume of flow used in the calculation was typically obtained from the landfill operator, with flow measurements most often measured using accumulating flow meters. The reported flow volumes should be considered approximate.

Table 2 presents average and peak LCRS and LDS flow rates for the "initial period of operation" and the "active period of operation", as defined by Bonaparte et al. [1996]. None of the units shown in Table 2 has received a final cover system over its entire area. As shown in Table 2, three different top liner/LDS combinations are represented, as follows:

- Group I: geomembrane/CCL composite top liner and granular LDS (two units from two landfills);

- Group II: geomembrane/CCL composite top liner and geosynthetic LDS (seven units from five landfills); and

Table 2. Description of landfill liner system components.

Landfill	Top Liner/	LCRS		Top Liner			LDS		Bottom Liner		
ID	LDS Group	Material[(1)]	Thickness (mm)	Geomembrane[(2)] Type (and Thickness (mm))	Lower Component		Material	Thickness (mm)	Geomembrane[(2)] Type (and Thickness (mm))	Lower Component	
					Material[(3)]	Thickness (mm)				Material[(3)]	Thickness (mm)
B	I	Sand	450	CSPE(0.9)	CCL	600	Sand	450	PVC(0.8)	NA[(5)]	NA
Y	I	Sand	600	HDPE(2.0)	CCL	450	Sand	300	HDPE(2.0)	CCL	600
AK	II	Sand/GN	600/5	HDPE(1.5)	GCL/CCL	6/600	GN	5	HDPE(1.5)	GCL	6
AL	II	Sand	600	HDPE(1.5)	CCL	900	GN	5	HDPE(1.5)	CCL	900
AM	II	Gravel/Sand	300/150	HDPE(2.0)	CCL	450	GN	5	HDPE(1.5)	NA	NA
AO	II	Sand	600	HDPE(1.5)	CCL	900	GN	5	HDPE(1.5)	CCL	600
AR	II	Gravel/TC	300/400	HDPE(1.5)	GCL/CCL	6/300	GN	10	HDPE(1.5)	CCL	600
AZ	III	Sand	600	HDPE(1.5)	GCL	6	GN	5	HDPE(1.5)	CCL	900

Notes: (1) LCRS Material: GN = Geonet or Geocomposite; TC = Tire Chips.

(2) Geomembrane Types: HDPE = High Density Polyethylene; CSPE = Chlorosulfonated Polyethylene; PVC = Polyvinyl Chloride.

(3) CCL = Compacted Clay Liner; GCL = Geosynthetic Clay Liner.

(4) All material thicknesses are nominal values.

(5) NA = not applicable.

Table 3. Summary of flow data for the LCRS and LDS of units with composite top liners.

Unit No.	Unit Area (hectare)	Start of Waste Placem. (month-year)	Initial Period of Operation[1] Time Period (months)	Initial: LCRS Flow[3] Avg. (lphd)	Initial: LCRS Flow[3] Peak (lphd)	Initial: LDS Flow Avg. (lphd)	Initial: LDS Flow Peak (lphd)	Active Period of Operation[2] Time Period (months)	Active: LCRS Flow Avg. (lphd)	Active: LCRS Flow Peak (lphd)	Active: LDS Flow Avg. (lphd)	Active: LDS Flow Peak (lphd)
B3[4]	6.4	7-87	1-4	15,304	24,858	1,394.2	4,250.0	5-16	5,700	8,935	124.1	265.5
								17-28	9,272	22,444	100.8	168.3
								29-40	7,575	13,978	262.4	803.0
								41-52	2,859	6,043	230.6	713.4
								53-64	1,189	2,280	44.8	151.5
								65-76	403	490	91.5	132.8
								77-88	560	919	101.9	192.6
								89-93	578	648	98.0	108.5
Y2	3	1-91	1-10	23,368	36,791	655.0	1,768.3	11-22	10,353	19,204	370.0	1992.8
								23-34	11,344	25,309	89.9	167.8
								35-46	4,404	6,380	69.6	247.8
								47-54	4,397	5,199	47.6	56.1
AK1	1.4	10-93	7-18	9,867	17,986	206.0	804.0					
AL1	14.9	1990	1-41	ND[5]	ND	ND	ND	42-53	934	2,085	230.6	366.5
								54-66	1,349	5,885	102.9	183.3
AM1	3.2/2.4[6]	10-90	1-9	ND	ND	ND	ND	10-21	270	533	15.0	63.7
								22-33	236	329	10.0	14.7
								34-45	111	283	3.0	14.2
								46-58	18	77	0.0	0.0

Table 3. Summary of flow data for the LCRS and LDS of units with composite top liners (cont.).

Unit No.	Unit Area (hectare)	Start of Waste Placem. (month-year)	Initial Period of Operation[1] Time Period (months)	Initial: LCRS Flow[3] Avg. (lphd)	Initial: LCRS Flow[3] Peak (lphd)	Initial: LDS Flow Avg. (lphd)	Initial: LDS Flow Peak (lphd)	Active Period of Operation[2] Time Period (months)	Active: LCRS Flow Avg. (lphd)	Active: LCRS Flow Peak (lphd)	Active: LDS Flow Avg. (lphd)	Active: LDS Flow Peak (lphd)
AM2	4.8/2.4[6]	10-90	1-9	ND	ND	ND	ND	10-21	32	154	9.0	42.4
								22-33	35	51	9.0	29.0
								34-45	17	45	3.0	26.0
								46-58	65	274	0.0	0.0
AO1	1.8	1-92	1-5	ND	ND	ND	ND	6-17	1,984	4,130	184.0	353.0
								18-29	1,299	1,577	96.4	126.0
								30-37	1,144	1,371	59.9	102.0
AO2	1.8	7-92	1-5	15,881	24,541	148.7	191.0	6-17	3,027	5,266	110.1	158.0
								18-31	1,688	2,383	32.5	63.8
AR1	9.7	3-92	1-11	27,042	65,871	291.8	705.0	12-23	11,251	23,384	180.7	470.0
								24-36	9,668	26,274	154.8	442.0
AZ1	3.8	12-92	2-13	4,173	5,219	0.0	0.0	14-21	3,889	5,053	3.6	22.4
								22-31	2,632	3,016	0.7	3.3

Notes:

(1) "Initial Period of Operation" represents period after waste placement has started and not more than a few lifts of waste and daily cover have been placed in the cell (i.e., no intermediate cover).

(2) "Active Period of Operation" represents period when waste thickness in cell is significant and/or an effective intermediate cover is placed on the waste.

(3) Flow rates are given in liter/hectare/day.

(4) 65 percent of Unit B3 received final cover after 60 months of start of waste placement.

(5) ND = not determined.

(6) Areas given represent LCRS and LDS areas, respectively.

- Group III: geomembrane/GCL composite top liner and geosynthetic LDS (one unit from one landfill).

Table 4 summarizes average values for 29 parameters which describe the liquid chemistry of the LCRS and LDS of the landfills described in Tables 2 and 3. The 29 parameters include water chemistry parameters (e.g., pH, specific conductance) and concentrations of select inorganic ions, metals, and volatile organic compounds. In calculating the average value for each parameter, half of the test detection limit was used for all readings reported as nondetects. If more than half of the measurements for a parameter were reported as nondetects, the calculated average value is proceeded by a "<" sign in Table 4. As with the flow rate data, the chemistry data were obtained from the landfill operator.

Analysis of Flow Rate Data

Table 3 shows that LCRS and LDS flow rates decrease significantly with time. Between the initial period of operation and later stages of the active period of operation, flow rates (for both LCRS and LDS) decreased up to two orders of magnitude. Reported peak LCRS flow rates were up to five times the average, while peak LDS flow rates were up to nine times the average. Measured LCRS flow rates ranged from (on average) 4,173 to 27,042 lphd during the initial period of operation and from 17 to 11,344 lphd during the active period of operation. For the LDS, average flow rates ranged from 149 to 1,394 lphd during the initial period of operation and from 0 to 370 lphd during the active period of operation.

Unit AZ1, which is the only unit in the database which includes a composite liner with a GCL lower component (i.e., Group III liner), exhibited much lower LDS flow rates than the other units with a CCL as a lower component to the composite liner (i.e., Group I and II Liners). The calculated LDS flow rates were on average less than 4 lphd. These lower flow rates are attributable to the limited amount of consolidation water that a GCL may yield versus a CCL. A CCL may yield significant amounts of consolidation water for a long period of time depending on the clay material, initial placement conditions (i.e., water content and dry density), and overburden pressure. Therefore, LDS liquid chemistry analysis, as described below, is important in assessing the extent to which leakage has occurred through the composite liner. Comparison between the LDS and LCRS flow rates for unit AZ1 suggests the top composite liner has a hydraulic efficiency greater than 99.9 percent.

Table 4. Summary of liquid chemistry for the LCRS and LDS of MSW landfills with top composite liners.

Landfill ID		B		Y		AK		AL	
Unit No.-System		B3-LCRS	B3-LDS	Y2-LCRS	Y2-LDS	AK1-LCRS	AK1-LDS	AL1-LCRS	AL1-LDS
Waste Placement Period		07/87-05/92		1990-date		10/93-date		1990 - date	
Liquid Sampling Period		07/87-10/94	05/87-10/94	04/91-04/94	04/91-04/94	12/93-03/95	12/93-03/95	06/91-05/95	12/89-05/95
Parameter	Units								
pH		6.82		6.60	7.28	6.65	7.20	8.09	7.04
Specific Conductance	µmhos/cm	2,956	1,554	5,360	1,583	1,592	679	2,707	2,449
Alkalinity	mg/l			2,520	335	711	8.1	< 261	199
TDS	mg/l	4,140	1,148	4,939	881			2,892	2,482
COD	mg/l	1,912	131	5,265	50	1,062	10	860	< 11
BOD,	mg/l	422	88	2,076	3.4	< 2.0		1,134	< 2.3
TOC	mg/l	554	138	1,436	11	245	0.45	245	2.8
Sulfate	mg/l	131	335	108	231	45	7.0	219	1,028
Calcium	mg/l			1,994	179	387	1.0	150	465
Magnesium	mg/l				54	51	1.0	98	121
Sodium	mg/l	450	46	433	46	64	1.0	236	38
Chloride	mg/l	3,929	127	605	58	94	1.4	430	151
Arsenic	µg/l		< 24	17	4.0	< 3.0	< 1.0	3.9	< 4.6
Lead	µg/l	< 44	< 17	5.0	8.0	< 48	< 1.0	< 36	< 17
Chromium	µg/l	49	3.3	58	11	< 27	< 1.0	< 64	< 9.6
Nickel	µg/l	102	519	185	25	< 50	< 50	57	< 35
Cadmium	µg/l	< 20	16	8.4	< 2.0	< 19	< 2.6	< 11	< 7.5
1,1,1 - Trichloroethane	µg/l	< 107	< 6.1			134	1.8	< 8.1	< 4.1
1,1 - Dichloroethane	µg/l	< 40	< 6.8	45		46	< 1.0	< 8.0	< 7.3
1,2 - Dichloroethane	µg/l	< 5.5	< 5.7			< 1.6	< 1.0	< 5.6	< 1.7
Benzene	µg/l	< 5.1	< 6.8	10		< 5.3	< 1.0	< 5.8	< 2.4
Ethylbenzene	µg/l	15	< 6.5	118		< 6.9	< 1.0	< 12	< 1.7
Methylene Chloride	µg/l	< 80	< 17	121		603	< 5.0	245	< 77
Trichloroethene	µg/l			11	7.0	< 1.4	< 1.0	< 12	< 2.1
Toluene	µg/l	< 78	< 9.3	720		95	< 1.0	78	< 6.8
Vinyl Chloride	µg/l	< 9.9	< 12			< 11	< 5.0	< 11	< 5.0
Xylenes	µg/l			69		< 30	< 3.0	< 96	< 4.9
Cis- 1,2-Dichloroethene	µg/l					< 1.2	< 1.0	< 6.5	< 3.0
Trans- 1,2-Dichloroethene	µg/l					< 1.0	< 1.0	< 2.1	< 1.8

Table 4. Summary of liquid chemistry for the LCRS and LDS of MSW landfills with top composite liners (cont.).

Landfill ID		AM				AO		
Unit No.-System		AM1-LCRS	AM1-LDS	AM2-LCRS	AM2-LDS	AO-LCRS	AO1-LDS	AO2-LDS
Waste Placement Dates		10/90-02/91		10/90-02/91		01/92-date		
Liquid Sampling Dates		04/91-02/95	02/92-12/93	04/91-01/95	02/92-02/95	08/92-06/95	08/92-05/95	08/92-06/95
Parameter	Units							
pH		6.61	6.90	6.60	7.26	7.30	7.17	6.69
Specific Conductance	µmhos/cm	2,519	17,250	2,471	16,975	6,592	1,132	829
Alkalinity	mg/l	1,209	407	987	163	1,756	556	964
TDS	mg/l	1,754	14,330	1,625	14,450	2,178	690	561
COD	mg/l	72	85	72	89	618	142	718
BOD,	mg/l							
TOC	mg/l	22	10	26	6	414	43	417
Sulfate	mg/l	19	1,500	15	1,446	54	44	8
Calcium	mg/l	372	1,470	340	1,840	275	205	91
Magnesium	mg/l	96	283	77	292	146	66	130
Sodium	mg/l	92	1,846	88	1,915	786	19	112
Chloride	mg/l	204	2,725	331	2,675	862	38	25
Arsenic	µg/l	72	< 2.0	36	< 7.0	45	6.9	17.6
Lead	µg/l	< 2.0	200	7	< 14	< 32	< 1.0	< 21.4
Chromium	µg/l	< 17	< 30	< 30	< 30	54	< 1.0	< 2.1
Nickel	µg/l	240	< 40	2.3	< 40	108	< 50	< 1
Cadmium	µg/l	< 20	< 20	< 20	< 10	< 9.3	< 0.38	< 19.29
1,1,1 - Trichloroethane	µg/l	< 16	< 1.0	19	< 1.0	< 11	< 4.0	< 29.3
1,1 - Dichloroethane	µg/l	146	< 2.6	187	< 1.0	15	< 2.8	< 1.2
1,2 - Dichloroethane	µg/l	5.2	< 1.0	9.0	< 1.0	< 5.3	< 6.4	< 3.0
Benzene	µg/l	15	< 1.1	17	< 1.0	6.8	< 2.4	< 3.3
Ethylbenzene	µg/l	55	< 1.0	35	< 1.0	11	< 2.5	< 3.3
Methylene Chloride	µg/l	< 6	3.3	61	< 1.5	75	< 6.5	< 3.3
Trichloroethene	µg/l	3.3	< 1.0	265	< 1.0	< 4.1	[illegible]	< 2.7
Toluene	µg/l	246	< 1.2	167	< 1.0	167	< 86	< 6
Vinyl Chloride	µg/l	< 6.0	< 1.0	< 14	< 1.5	< 12	< 7.0	< 4.3
Xylenes	µg/l	112	< 1.4	77	< 1.5	34	< 5.4	< 3.0
Cis- 1,2-Dichloroethene	µg/l	322	< 1.0	870	< 1.0	< 5.9	< 2.5	< 4.7
Trans- 1,2-Dichloroethene	µg/l	< 6.0	< 1.0	< 9.0	< 1.0	< 4.0	< 2.5	< 7.6

Table 4. Summary of liquid chemistry for the LCRS and LDS of MSW landfills with top composite liners (cont.).

Landfill ID		AR		AZ	
Unit No.-System		AR1-LCRS	AR1-LDS	AZ1-LCRS	AZ1-LDS
Waste Placement Dates		03/92-date		12/92 - date	
Liquid Sampling Dates		11/92-08/94	11/92-08/94	09/93-03/95	06/93-03/95
Parameter	Units				
pH		6.93	6.80	6.14	6.60
Specific Conductance	µmhos/cm	6,067	1,240	4,810	5,235
Alkalinity	mg/l	1,767	287	1,445	1,183
TDS	mg/l	3,230	797	5,200	3,570
COD	mg/l	1,232	9.8		154
BOD_5	mg/l	260	3.5	2,890	
TOC	mg/l	355	4.0	1,009	55
Sulfate	mg/l	310	313	< 7.0	1,065
Calcium	mg/l	245	184	660	133
Magnesium	mg/l	154	143	106	39
Sodium	mg/l	617	16	328	1,102
Chloride	mg/l	1,267	22	617	57
Arsenic	µg/l		< 7.5	< 12	235
Lead	µg/l	15	< 8.3	< 3.5	8.0
Chromium	µg/l		< 10	< 37	< 8.0
Nickel	µg/l	< 20	< 100	< 132	< 40
Cadmium	µg/l	< 5.5	< 5.3	< 15	1.7
1,1,1 - Trichloroethane	µg/l	< 100	< 2.0	270	< 8.7
1,1 - Dichloroethane	µg/l	< 100	< 2.0	170	11
1,2 - Dichloroethane	µg/l	< 100	< 2.0	< 80	< 2.7
Benzene	µg/l	< 100	< 0.50	< 80	< 2.3
Ethylbenzene	µg/l	< 100	< 2.0	< 90	< 2.7
Methylene Chloride	µg/l	< 100	< 2.0	4,150	29
Trichloroethene	µg/l	< 100	< 2.0	< 90	< 2.7
Toluene	µg/l	< 100	< 2.0	275	< 2.7
Vinyl Chloride	µg/l	< 100	< 4.0	< 300	< 7.7
Xylenes	µg/l	< 100	< 4.0	< 170	< 4.3
Cis- 1,2-Dichloroethene	µg/l	< 100	< 50	< 120	< 4.3
Trans- 1,2-Dichloroethene	µg/l	< 100	< 2.0	< 110	< 4.3

Analysis of Chemical Data

Chemical parameters for LDS liquid are compared to the same parameters for the LCRS liquid in Table 4. In evaluating the chemical data, several factors were considered including: (i) solubility and adsorptive characteristics of the chemical; (ii) potential for biological or chemical degradation of the chemical; (iii) dilution of the chemical due to mixing with consolidation or compression water; and (iv) natural occurrence of the chemical. In comparing the LCRS and LDS liquid quality data shown in Table 4, greater consideration was given to chemicals that were detected in significant levels in the LCRS and that have high mobility and persistence (i.e., low sorption and biological or chemical decay). Chloride, sulfate, vinyl chloride, benzene, methylene chloride, and toluene meet these criteria.

As shown in Table 4, the LDS liquid quality appears to be significantly different than the LCRS liquid quality for all the MSW landfills considered. Liquid quality indicators such as specific conductance, alkalinity, TDS, COD, BOD, and TOC are lower for LDS liquids than LCRS liquids. This observation also holds when comparing concentrations of organic compounds. In general, VOCs were detected in the LDS liquids in only a few instances. In these instances, the VOC concentrations were very low (i.e., in the low parts per billion (ppb) range). This evidence suggests that no significant leakage occurs through the composite liners for the monitoring periods considered.

To further evaluate the above conclusion, Piper [1944] trilinear diagrams were produced for the units included in Table 4. The Piper trilinear diagram incorporates a combination of anion and cation concentrations to graphically describe liquid composition. This diagram is commonly used in ground-water studies. Figures 3 through 9 show the Piper trilinear diagrams for the units described in Table 4. As shown in these figures, LCRS and LDS liquid chemistry for the units appear to be significantly different. This is evident by the difference in location on the two-coordinate diagram representing each system and by the difference in diameter of the circle representing total dissolved solids for each system. These Piper diagrams give further evidence that no significant leakage occurs through composite liners.

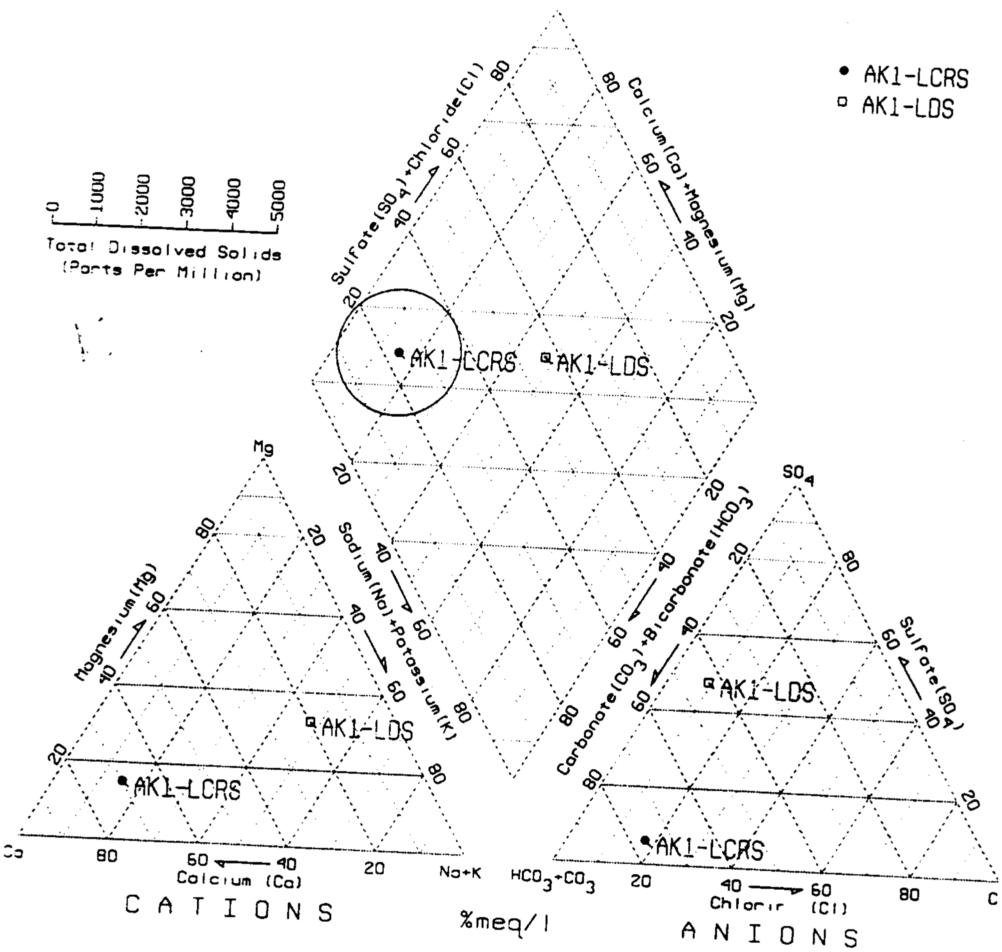

Figure 3. Piper trilinear diagram for unit AK1.

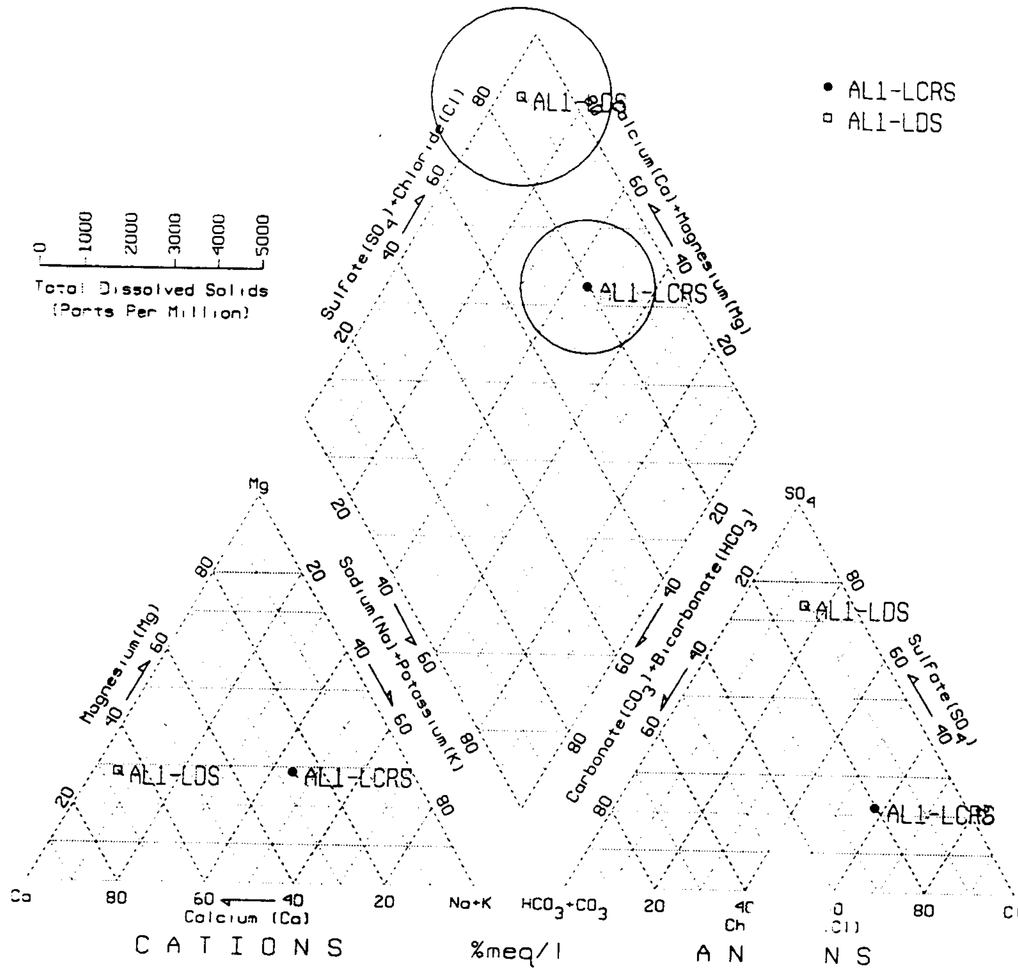

Figure 4. Piper trilinear diagram for unit AL1.

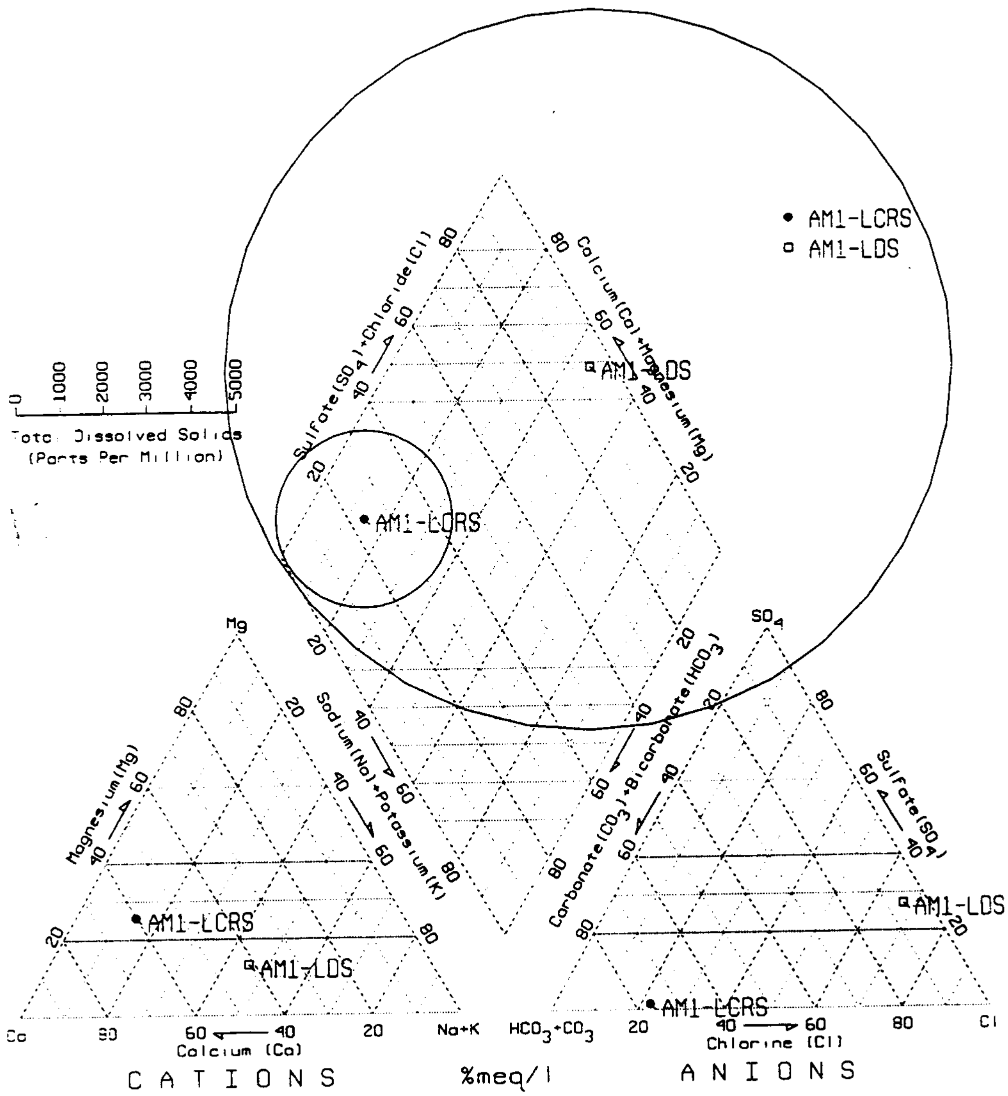

Figure 5. Piper trilinear diagram for unit AM1.

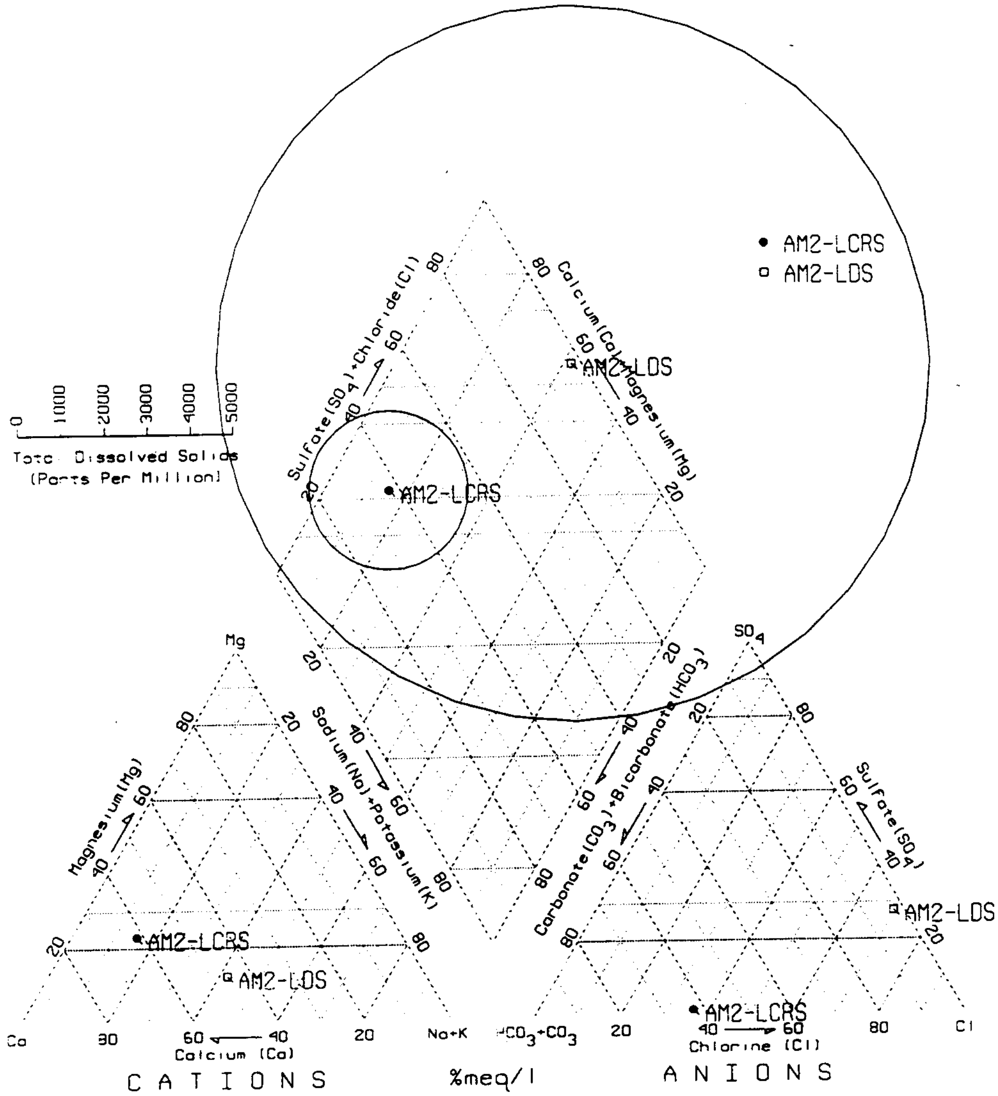

Figure 6. Piper trilinear diagram for unit AM2.

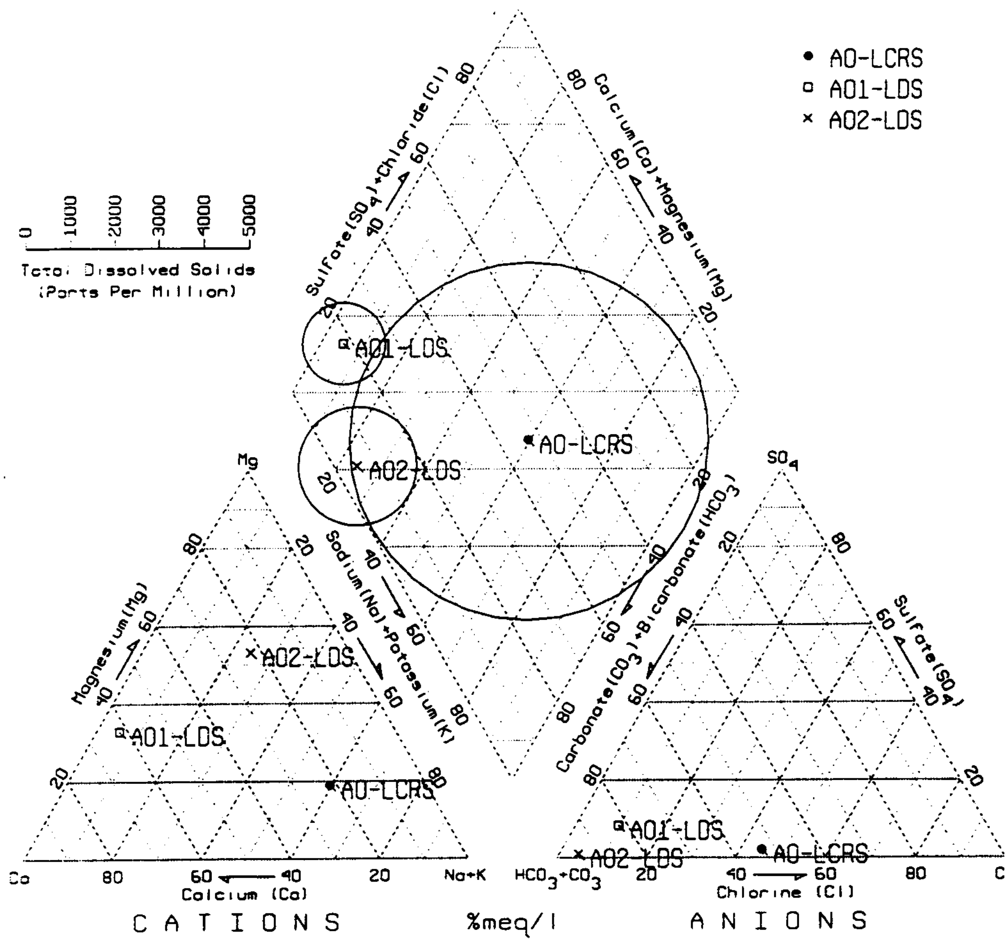

Figure 7. Piper trilinear diagram for units AO1 and AO2.

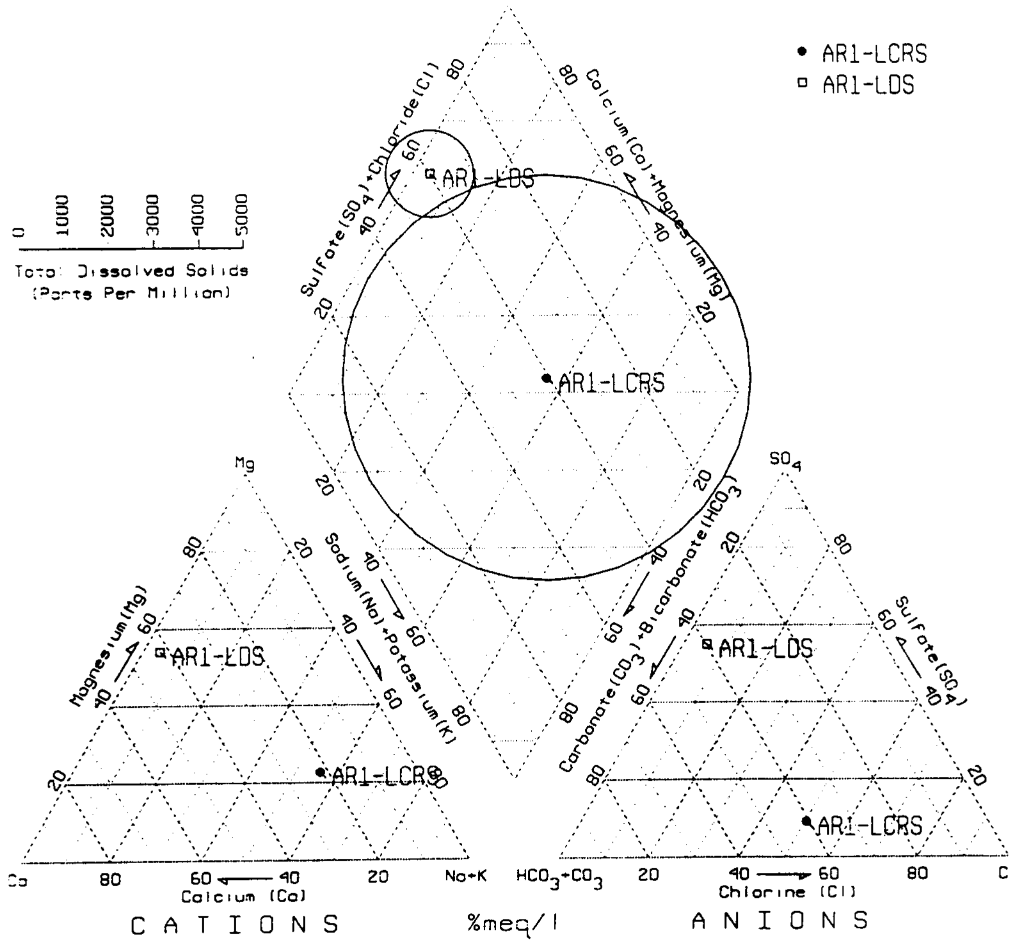

Figure 8. Piper trilinear diagram for unit AR1.

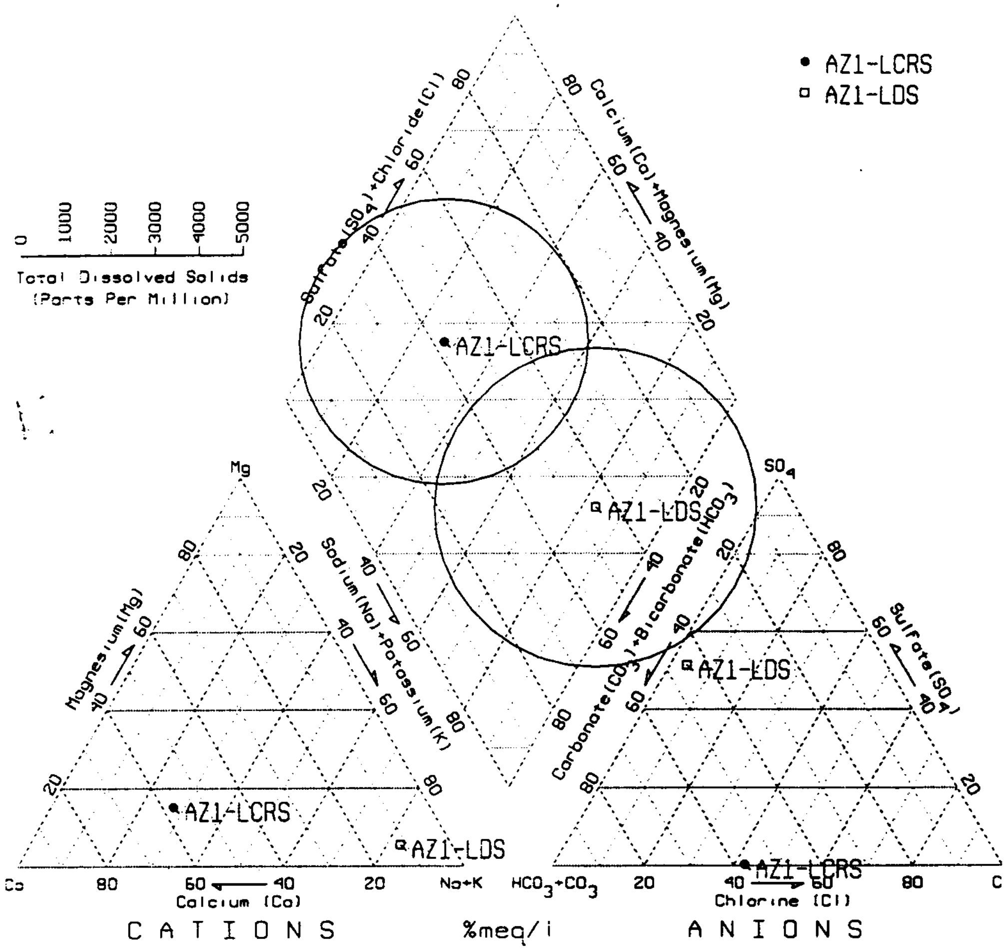

Figure 9. Piper trilinear diagram for unit AZ1.

SUMMARY AND CONCLUSIONS

This paper presented preliminary results of a study of composite liner field performance. Performance was evaluated by studying flow rates and flow constituents of the LCRSs and LDSs of ten double-lined MSW landfills. The major findings of this study are summarized below.

- LCRS and LDS flow rates decrease significantly with time; between the initial period of operation and the active period of operation, LCRS and LDS flow rates may decrease up to two orders of magnitude. Peak LCRS flow rates are up to five times the average, while peak LDS flow rates are up to nine times the average.

- Measured LCRS flow rates ranged on average from 4,173 to 27,042 lphd during the initial period of operation and from 17 to 11,344 lphd during the active period of operation.

- LDSs underlying composite liners with a CCL lower component exhibited average flow rates of 149 to 1,394 lphd during the initial period of operation and 0 to 370 lphd during the active period of operation.

- The LDS underlying a composite liner with a GCL lower component exhibited average flow rates of 0 to 4 lphd. The hydraulic efficiency of this top composite liner was calculated to be greater than 99.9 percent.

- chemical analyses of LCRS and LDS liquids show them to be very different indicating that no significant leakage occurs through composite liners with a CCL or a GCL lower component.

The above findings are consistent with previous studies conducted by the authors and by other researchers which suggest that composite liners with a CCL lower component always exhibit significant flow while composite liners with a GCL lower component exhibit very little flow. Due to the virtual omnipresence of consolidation water in LDSs underlying composite liners containing CCLs, it has thus far not been possible to definitively quantify, using operational data, leakage rates through this type of composite liner. The presence of consolidation water will tend to mask any small amounts of leakage through the liner. However, it is not unreasonable to suggest that leakage rates through composite liners containing CCLs may not be much different than composite liners containing GCLs. This suggestion is consistent with the results obtained from comparative liner leakage calculations (e.g., Giroud et al. [1994]; Bonaparte and Giroud [1996]). This suggestion is also consistent with the general concept of composite liner "equivalency" as described by Koerner and Daniel [1994]. It is assumed that composite liners containing CCLs are equivalent to composite liners containing GCLs. The true hydraulic efficiency of both types of liners, assuming proper liner system design and construction, is greater than 99.90 percent.

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